High p_T hadron spectra in high-energy heavy-ion collisions *

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At low p_T the pQCQ parton model becomes invalid and other alternative approaches like thermal fire-ball models have to be used, from which one can extract the freeze-out temperature, collective radial flow velocity and chemical potential. Apparently, these thermal fire-ball models cannot be applied to describe hadron spectra at large p_T. Therefore, it is very important to investigate how well a pQCD parton model can describe hadron spectra in pp collisions and their modification in pA and AA collisions and where the transition happens between hard and soft hadron production. In particular, the impact-parameter or A dependence of the spectra may be unique to distinguish the parton model from other thermal fire-ball or hydrodynamic models. One can then at least make a quantitative conclusion about the validity of different models at different p_T range. The values of temperature and flow velocity extracted from a fire-ball model analysis, for example, will have to be looked at with caution and knowledge of limitations.

We assume that the inclusive differential cross section for large p_T particle production in pA and AA is given by the hard parton-parton scattering as in pp collisions, except that the initial transverse momentum k_T of the beam partons is broadened. Assuming that each scattering provide a k_T kick which also has a Gaussian distribution, we can in effect just change the width of the initial k_T distribution,

$$\langle k_T^2\rangle_A(Q^2) = \langle k_T^2\rangle_N(Q^2) + \delta^2(Q^2)(\nu_A(b)-1). \tag{1}$$

The broadening is assumed to be proportional to the number of scattering $\nu_A(b)$ the projectile suffers inside the nucleus. We will use the following k_T broadening per nucleon-nucleon collision,

$$\delta^2(Q^2) = 0.225\frac{\ln^2(Q/\mathrm{GeV})}{1+\ln(Q/\mathrm{GeV})} \quad \mathrm{GeV}^2/c^2. \tag{2}$$

The p_T dependence of the broadening reflects the fact that the distribution of soft k_T kick for each scattering does not necessarily have a Gaussian form. The above calculation has been shown to reproduce the nuclear modification of the hadron spectra in pA data very well.

According to the pQCD parton model, the hadron spectra at large p_T should scale with the number of binary nucleon-nucleon collisions if no nuclear effect is included. So if one defines a ratio,

$$R_{AB}(p_T) \equiv \frac{d\sigma^h_{AB}/dyd^2p_T}{\langle N_{\rm binary}\rangle d\sigma^h_{pp}/dyd^2p_T} \tag{3}$$

between spectra in AB and NN collisions normalized by the averaged number of binary collisions $\langle N_{\rm binary}\rangle$, the ratio will be approximately one for spectra from hard parton collisions. Because of absorptive processes, low p_T particle production has much weaker A-dependence. In the wounded-nucleon model, soft particle production is proportional to the average number of wounded nucleons, the above ratio will become

$$R_{AB} \sim 0.5(1/A^{1/3}+1/B^{1/3}) \tag{4}$$

So the ratio as defined in Eq. (3) will be smaller than one at low p_T and larger than one at large p_T. Such a general feature has been found to be almost universal in both pA and AB collisions.

At even higher p_T, the effect of multiple scattering becomes less important, so the ratio R_{AB} will approach to 1 again (higher twist effect should be suppressed by $1/p_T^2$). However, at SPS energy, such a feature cannot be be fully revealed because of the kinetic limit. One will then only see the initial increase of the ratio due to the transition from soft to hard processes. Such a change of spectra from pp to pA and AA collisions in a limited kinetic range looks very similar to the effect of collective flow in a hydrodynamic model. However, models motivated by parton scattering have definite A-dependence of such a nuclear modification. Therefore one should take caution about the values of temperature and flow velocity extracted from such a fire-ball analysis of the spectra, especially if one has to reply on the shape of the spectra in the p_T region around 1 GeV.

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